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Development of a metric technique for identification of rib number (position) in white-tailed deer (*Odocoileus virginianus*): an initial attempt

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ABSTRACT

Zooarchaeologists have traditionally largely ignored ungulate ribs because they are seldom identifiable to genus or species, and they cannot be sorted as to which rib is represented (first, seventh, twelfth). Measurements of six dimensions of 287 ribs from 15 individual white-tailed deer (*Odocoileus virginianus*) reveal that four dimensions do not differentiate ribs as to position. The ratio of costal facet height to costal facet width, however, gives a >90 percent chance of correctly categorizing proximal ribs as either anterior (ribs 1–6) or posterior (ribs 9–13). Future research should incorporate frequencies of anterior and posterior ribs into studies of skeletal part frequencies. The metric technique of rib seriation could be applicable to other ungulate taxa.

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1. Introduction

Ribs of mammals are frequently disregarded in zooarchaeology, apparently due to our inability to identify their genus or species affiliation. For this reason mammal ribs in particular have been characterized as having low analytical value relative to other bones (e.g., Olsen, 1961, 1971; White, 1953, 1956). The fact that osteology guides and skeletal keys describe or illustrate nearly all appendicular elements and at least some axial elements of mammals in detail yet omit ribs from discussion and illustration not only reflects but perpetuates the belief that ribs are of little analytical value (Amorosi, 1989; Brown and Gustafson, 1979; Gilbert, 1990; Hillson, 1992; Lawrence, 1953; Luff, 1984; Olsen, 1973; Schmid, 1972; Smith, 1979). Exacerbating this perception is the fact that the body side represented by particular ribs is not required knowledge in some analytical techniques that include ribs (Klein and Cruz-Uribe, 1984:109). In other cases all ribs are grouped together as a single anatomical unit and not distinguished as to particular rib (first, third, seventh, etc.), such as in the well-known analytical techniques that focus on the frequencies of different skeletal parts (e.g., Binford, 1978). Despite the perceived low status of mammalian ribs

among zooarchaeologists, they could play a key role in some analyses.

By treating all ribs as the same, we may be masking significant variation in one or more taphonomic variables. For instance, the patterned sequence in which an ungulate carcass is consumed by carnivores involves eating from the posterior toward the anterior end (Blumenschine, 1986; Burgett, 1990; Haynes, 1982). Descriptions of that sequence hint at the possibility that posterior ribs will be consumed before anterior ribs. Thus noting whether both anterior and posterior ribs or only anterior ribs are present in a carnivore-gnawed collection may suggest how extensively carcasses had been ravaged by carnivores. It seems, then, that if an analytical technique could be developed that allowed distinction of the taxon represented by a rib (see next paragraph), or that allowed distinction of the particular rib represented by a zooarchaeological specimen, or both, we may gain much insight to human behaviors and other taphonomic processes.

As noted above, identification of the genus or species represented by ribs is, at present, virtually impossible for many mammals. We note, however, that as recently as a decade ago many zooarchaeologists working in North America believed it impossible to distinguish post-cranial remains of white-tailed deer (*Odocoileus virginianus*) from remains of the congeneric mule deer (*Odocoileus hemionus*). After close inspection of numerous skeletons of each species, Jacobson (2004) showed that in fact a number of the

skeletal elements of North American *Odocoileus* could be identified to species. The history of North American zooarchaeology includes a number of such instances. We take this as an indication that, as time passes, we may well learn how to distinguish ribs of *Odocoileus* from those species of similar body size such as pronghorn (*Antilocapra americana*) and bighorn sheep (*Ovis canadensis*). As part of this study, a brief comparison of ribs of *Odocoileus* and *Antilocapra* by Lyman revealed no readily apparent morphometric differences. Hence developing a technique to determine rib number among zooarchaeological specimens became our first goal as it seemed to have greater potential for success than developing taxonomically diagnostic criteria. Ironically, the ribs of *Odocoileus* spp., *A. americana*, and *O. canadensis* may be so similar that the criteria (not just the method) allowing distinction of anterior from posterior *Odocoileus* ribs we describe could be applicable to all three genera. Future work will explore means to identify the species represented by a rib, and test our method of identifying deer rib position on ribs of pronghorn and bighorn sheep. What we describe below represents the initial phase of this research.

Development of a technique for distinguishing the particular rib represented by a specimen should be relatively straightforward. Ribs are paired bones that attach to the vertebral column and protect and support the viscera of the thorax. They provide protection for the spinal column, serve as locations for muscle attachments, and aid in respiration (Romer and Parsons, 1977; Steele and Bramblett, 1988). In mammals, each rib articulates to a demi-facet on the thoracic vertebrae. The size of the demi-facet varies between and within animals, decreasing in size posteriorly along the vertebral column. Distinctive morphometric features present on human and non-human mammalian vertebrae allow them to be distinguished from each other (e.g., cervical, thoracic, lumbar) and aid in the identification of the taxon represented (e.g., Amorosi, 1989; Balkwill and Cumbaa, 1992; Brown and Gustafson, 1979). Seldom described verbally, these vertebra- and taxon-specific morphometric features are apparent in illustrations and among comparative specimens (see Balkwill and Cumbaa (1992) for a rare example of verbal descriptions).

The anatomical association of ribs and vertebrae and the anatomical functions they serve suggest ribs may be distinguishable by position in the thorax; the first rib is the most dorsal or anterior, the tenth rib is more ventral or posterior. Human ribs are regularly distinguished as to anatomical position or number by forensic scientists. The techniques used to do so are often labeled "rib seriation." Rib seriation involves sorting anatomically complete human ribs into anatomical order based on size and curvature (e.g., Dudar, 1993; Hoppa and Saunders, 1998; Kim et al., 2009; Mann, 1993; Owers and Pastor, 2005). As an initial step toward developing techniques to enhance the analytical value of mammalian ribs, we here describe a metric technique that allows us to seriate ribs of a taxon into two positional categories—anterior and posterior. Although developed for one species of ungulate, the technique could be applicable to most ungulate taxa.

2. Materials and methods

White-tailed deer (*O. virginianus*) are widespread in the Americas. Their remains are numerous in archaeological sites and comparative skeletons are found in many natural history museums and in zooarchaeology comparative collections. We studied ribs (n = 287) of fifteen individual white-tailed deer; 12 were from Missouri, 2 from West Virginia, 1 from Washington. An individual deer has 26 ribs (13 lefts, 13 rights); not all rib sets from individual deer we examined were complete, hence fewer ribs than found in 15 complete rib sets (n of ribs = 390) were examined. The anatomical side was noted for each rib, and each set of left ribs and

each set of right ribs from each individual deer was seriated based on rib shape, length, and curvature of each rib. Sets of seriated ribs were then compared to a fully articulated white-tailed deer skeleton to confirm the ordering of rib sets. Each rib in the collection of 287 ribs was assigned a number (1 for anterior-most; 13 for posterior-most). Based on the principle of bilateral symmetry we assumed there would be no significant morphometric differences between left and right ribs. We measured all available ribs, both lefts and rights.

Zooarchaeological rib specimens with which we are familiar tend to be anatomically incomplete and made up of either the head or dorsal portion, and some middle or ventral portion. This seems to be the case in collections studied by others of both deer (e.g., Jacobson, 2004) and other, similarly sized ungulates such as bighorn sheep (*O. canadensis*) (e.g., Grayson, 1988; Thomas and Mayer, 1983). Rib heads have more anatomically diagnostic features and are easily sided (left or right) relative to some middle and particularly ventral rib fragments. Therefore, we defined six metric dimensions for the rib head, neck and costal facet (Fig. 1, Table 1). Measurements were taken with sliding calipers and recorded to the nearest 0.01 mm. Of the 287 ribs measured, all six dimensions could be measured on only 137 ribs. The majority of the ribs with an incomplete compliment of measurements were missing the rib neck and/or head as a result of predator activity or laboratory processing.

Principal component analysis (PCA) of the 137 complete ribs was performed using R (R Development Core Team 2008). Analyses of both untransformed data and log-transformed data (to normalize distributions) were performed. Each measurement for each rib was labeled as to rib number. The most heavily weighted dimensions identified by PCA were plotted against rib number and trend lines were determined. To control for size variability, ratios of the most heavily weighted dimensions were also calculated and plotted against rib number. Each dimension, each possible pair of
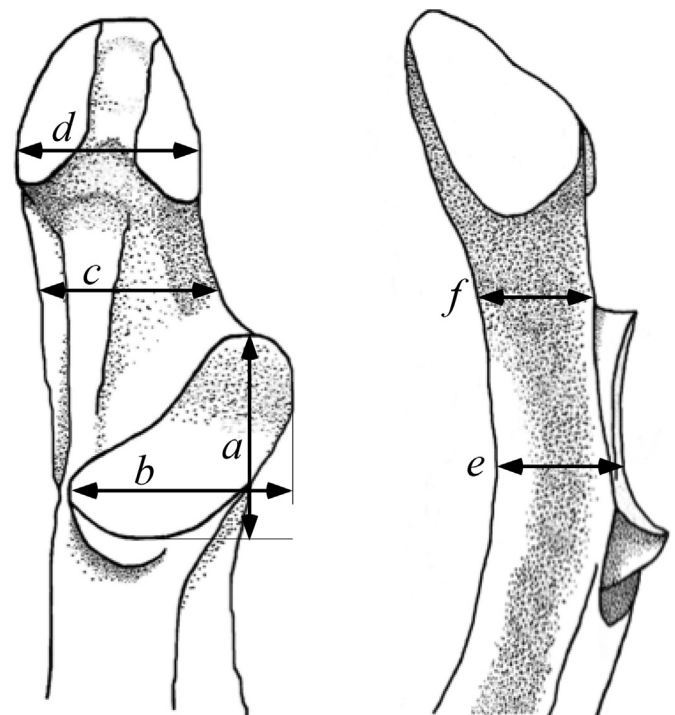

Fig. 1. Dimensions measured on the dorsal end of white-tailed deer (*Odocoileus virginianus*) rib (see Table 1). Left, ventral dorsal view; right, cranial–caudal view.

Table 1
Description of measured dimensions of white-tailed deer rib heads.

Dimension (Fig. 1)	Description
a	Height of the costal facet, parallel to the rib neck
b	Width of the costal facet, perpendicular to the rib neck
c	Width of the rib neck, at the narrowest point below (ventral to) the rib head
d	Width of the rib head, at the widest point on the plane parallel to the costal facet
e	Facet to rib depth, the lowest point of the coastal face to the base of the rib
f	Depth of the rib neck, perpendicular to dimension c

dimensions, and each possible ratio of two dimensions was examined. Only those that provide the most robust discrimination of rib number are described in the following.

3. Results

Three log-transformed dimensions—costal facet height (a), costal facet width (b), and facet to rib depth (e) (Fig. 1, Table 1)—have the most weight in the PCA; together these three dimensions explain 87% of the morphometric variability in dorsal rib ends. Because these three dimensions did not require the rib head and neck to be measured, data for all three dimensions for all 287 ribs were included in subsequent analyses. A bivariate plot of costal facet height (log transformed) against costal facet width (log transformed) reveals a cluster of anterior-most ribs 1 through 6 and a cluster of posterior-most ribs 8 through 13 (Fig. 2). Rib 7 represents a transition between the two clusters and could be associated with either the anterior or posterior compliment of ribs.

A plot of the three heavily weighted dimensions (a, b, e) against rib number was constructed in hopes that the plots would facilitate distinction of individual rib number. The plot of facet to rib depth (e) for individual ribs against rib number defined a U-shaped distribution that made it difficult to distinguish rib 5 from rib 10, so this dimension was omitted from analyses. On one hand, both the log of costal facet width (b) and the log of costal facet height (a) changed sufficiently continuously from rib number to rib number to not be reliably diagnostic of rib number (Fig. 3). The ratio of the log of costal facet height:log of costal facet width, on the other hand, distinguishes anterior ribs 1–6 from posterior ribs 9–13 fairly well (Fig. 4). The transition in the ratio is continuous from rib 1 to rib 13, but if the log facet height:log facet width ratio for a rib specimen is <1.0, odds are good that the rib is an anterior rib (rib
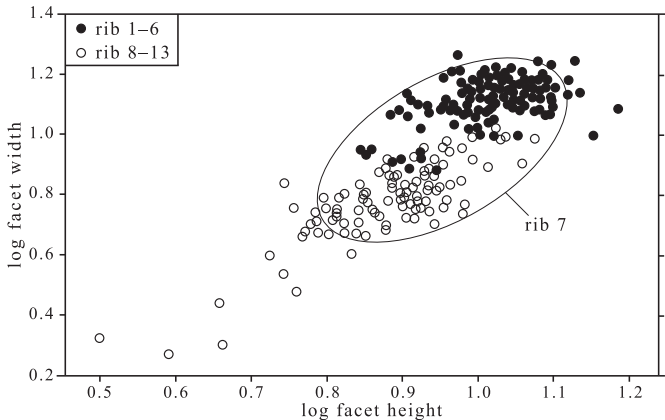

Fig. 3. Log rib costal facet height (a) and log rib costal facet width (b) plotted against rib number for white-tailed deer. Note the continuity in both dimensions across rib number.

1–6); 148 of 159 ribs 1 through 6, or 93.1%, display ratios <1.0. If the ratio is ≥1.0, odds are good that the rib is a posterior rib (rib 9–13); 74 of 75 ribs 9 through 13, or 98.7%, display ratios ≥1.0. Ribs 7 and 8 are not readily distinguished as to anterior or posterior category; 27 of 53 (51%) of these ribs have ratios <1.0 and the 26 (49%) remaining ribs have ratios ≥1.0.

The percentages of ribs that might be correctly identified in a zooarchaeological collection are suggested by the percentages

Fig. 2. Log costal facet height plotted against log costal facet width for anterior ribs (1–6) and posterior ribs (8–13) in white-tailed deer. Ellipse indicates distribution of rib 7 specimens (not plotted as individual ribs).
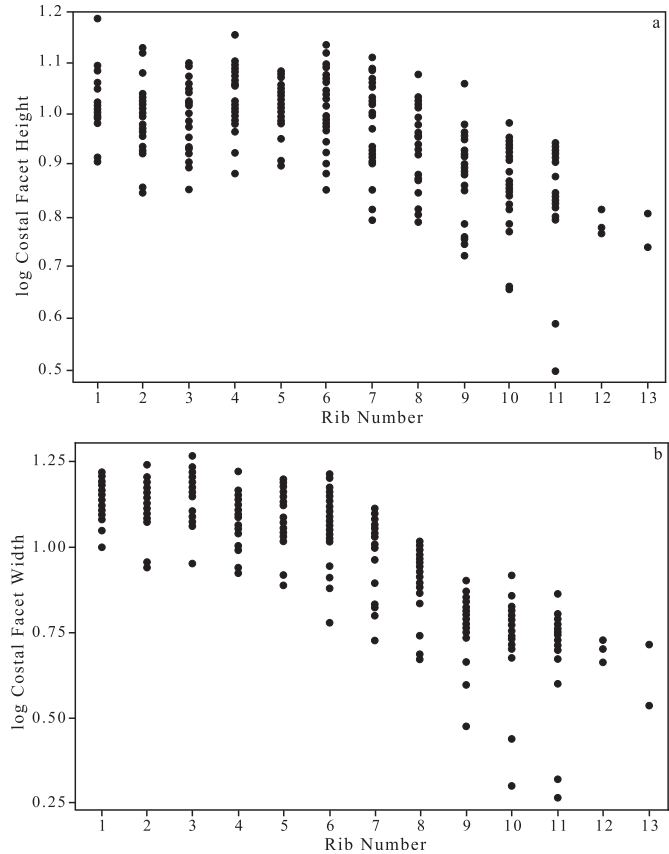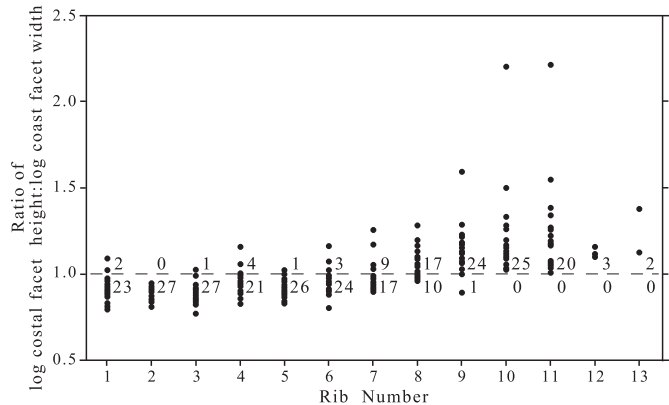

Fig. 4. Ratio of log rib costal facet height to log rib costal facet width plotted against rib number for white-tailed deer. Dashed line indicates a ratio of 1.0. Numbers above dashed line indicate frequency of ribs with ratio ≥1.0 for particular rib number; numbers below dashed line indicate frequency of ribs with ratio <1.0 for particular rib number.

of known ribs that are correctly categorized by the log of costal facet height to log of costal fact width ratio. Some analysts might be concerned that the percentages are <100%, suggesting a few zooarchaeological ribs might be incorrectly categorized as, say, anterior specimens when they are in reality posterior ribs. We note that there should be no cause for concern because zooarchaeologists regularly use morphometric anatomical features to identify the taxon of a specimen even though those features may only produce correct identifications ~90% of the time (e.g., Balkwill and Cumbaa, 1992; Jacobson, 2004). Even the increasingly popular (likely because it uses multiple dimensions) geometric morphometric techniques may produce identifications with a ~90% chance of being correct (e.g., McGuire, 2011).

We have been unable to consistently distinguish exact rib number using the six dimensions we measured (Fig. 1, Table 1). We are not, however, dismayed by this lack of resolution. The fact that we can distinguish anterior from posterior ribs of an ungulate based on a ratio of two straightforward (that is, easily conceived and reliably measured) dimensions suggests that other dimensions might be defined that allow confident determination of a particular rib head's precise number. Consider, for example, Fig. 5. The obvious morphometric differences between these three ribs—second, seventh, and tenth ribs—give us reason for our confidence. We note as well that once we had handled several sets of ribs, we came to easily recognize ribs 1 and 2, and also ribs 12 and 13 based on the morphology of the costal facet. The key issue, of course, is whether the metric technique we have developed can be applied to zooarchaeological specimens and what we might learn from an application. We address that issue in the following section.

4. A zooarchaeological application

Because identification of the species represented by a rib is currently not possible and because our rib number identification technique is based on white-tailed deer, a zooarchaeological assemblage that likely contained only remains of this species was preferred. Further, although it would have facilitated making our point that knowing whether an assemblage contains mostly anterior or mostly posterior ribs could be analytically significant, we had neither the time nor the resources to identify such an assemblage. Given these two limitations, we choose an assemblage known to contain only deer remains and that was analytically convenient.

Helmreich Shelter (23CP40) is a small rockshelter in central Missouri. It was excavated by members of the Missouri Archaeological Society in the 1960s. Sediments were removed in arbitrary levels as the ~1.3 m thick deposit was relatively homogeneous. Artifacts recovered from the site and two radiocarbon dates from near the bottom of the deposit suggest a late Archaic occupation (O'Brien and Wood, 1998). Deer (*Odocoileus* cf. *virginianus*) remains from the site were originally examined by Lyman in 1993 (total NISP = 887); he tallied 117 rib specimens of deer-size mammals. All recovered faunal remains are now being studied by students under Lyman's supervision. Rib heads of deer size were removed from the collection upon encounter and measured by Lyman for this study. We assume all ribs represent white-tailed deer as this is the only species of deer, and the only species of ungulate of this body size, documented in the local zooarchaeological record. A number of the deer remains have butchering marks in the form of cut marks or striae, and impact cones. Other specimens display unambiguous evidence of carnivore gnawing.

Fifty of the rib specimens from the site represent the dorsal end or rib head (Table 2). Of these, 20 could not be measured because the costal facet was incomplete as a result of fragmentation. The side (left, right) represented by three specimens could not be determined, resulting in this variable being recorded for 47 specimens. Thirty-three specimens represent lefts and 14 represent rights, a difference that is statistically significant (chi^2 = 7.68, p < .0005). Costal facets of only 30 specimens could be measured (Table 2). Of these, 17 ribs have log height:log width ratios <1.0 (are anterior ribs), 12 have a ratio >1.0 (are posterior ribs), and one has a ratio of 1.0 (cannot be categorized as anterior or posterior). There are more anterior ribs 1–6 than there are posterior ribs 9–13, but the difference is not statistically significant (chi^2 = 0.86, p > .2). Although there is evidence that some density-mediated attrition of deer remains has occurred (Fig. 6), density data for different ribs in an ungulate skeleton are not available. Assuming, then, that differential preservation has not influenced the frequencies of anterior (ribs 1–6) and posterior (ribs 9–13) ribs, we conclude that transport of deer ribs from the kill site to Helmreich shelter did not vary from the anterior to the posterior rib cage. Similarly, we conclude that differential density-mediated destruction has not influenced the relative abundances of anterior and posterior ribs.

5. Conclusions

Identification of rib number could be utilized to enhance measurement of the differential use and transport of portions of prey carcasses whether the economic utility models developed by Binford (1978) are used or not. As originally developed by Binford (1978), the modified general utility index or MGUI is the link between transport or use and the economic utility of a carcass's
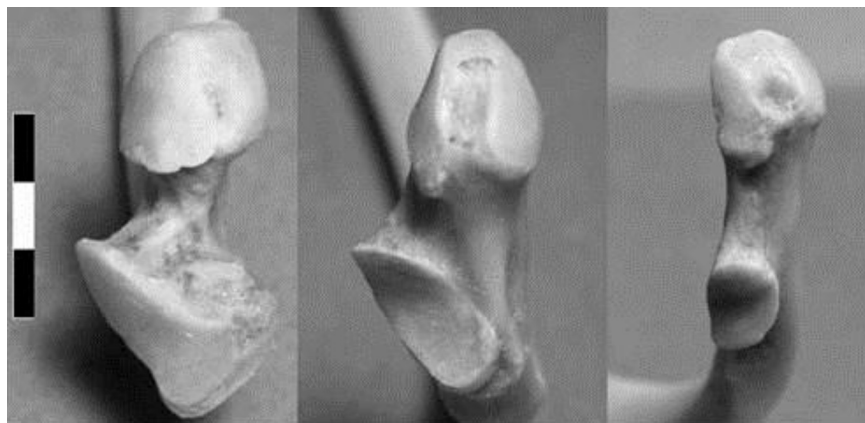

Fig. 5. Rib 2 (left), rib 7 (center), and rib 10 (right) from a white-tailed deer. Scale bar is 1.5 cm.

Table 2
Costal facet dimensions of white-tailed deer rib heads from Helmreich Shelter, Missouri. Values are observed and (log transformed).

Inventory number	Side	Height (mm)	Width (mm)	Ratio
1019	L	Broken		
1089	L	Broken		
1228	L	11.36 (1.056)	14.70 (1.167)	0.77 (0.905)
1356	?	Broken		
2045	L	Broken		
2046	L	12.18 (1.086)	10.96 (1.040)	1.11 (1.044)
2063	?	Broken		
2370	R	11.86 (1.074)	14.16 (1.151)	0.84 (0.933)
2560	L	14.06 (1.150)	16.54 (1.219)	0.85 (0.943)
2571	L	Broken		
2573	L	11.78 (1.071)	12.44 (1.095)	0.95 (0.978)
2773	R	Broken		
2783	R	9.14 (0.961)	10.70 (1.029)	0.85 (0.934)
3078	R	Broken		
3281	R	Broken		
3887	L	9.78 (0.990)	11.32 (1.054)	0.86 (0.939)
3962	L	14.30 (1.155)	11.40 (1.057)	1.25 (1.093)
4287	L	10.56 (1.024)	10.40 (1.017)	1.02 (1.007)
4725	R	9.86 (0.994)	5.72 (0.757)	1.72 (1.313)
4862	L	Broken		
4863	R	Broken		
4874	L	12.82 (1.108)	13.36 (1.126)	0.96 (0.984)
5167	L	Broken		
5202	L	9.52 (0.979)	10.02 (1.001)	0.95 (0.978)
5203	L	9.80 (0.991)	8.50 (0.929)	1.15 (1.067)
5646	L	12.14 (1.084)	10.08 (1.003)	1.20 (1.081)
5852	L	10.94 (1.039)	14.68 (1.167)	0.75 (0.890)
5992	L	Broken		
6255	L	Broken		
6314	L	10.30 (1.013)	8.76 (0.943)	1.18 (1.074)
6322	R	12.74 (1.105)	12.70 (1.104)	1.00 (1.001)
6676	?	Broken		
7118	L	15.28 (1.184)	17.78 (1.250)	0.86 (0.947)
7377	L	10.68 (1.029)	10.32 (1.014)	1.03 (1.015)
7722	R	10.10 (1.004)	7.58 (0.880)	1.33 (1.141)
8420	L	Broken		
9914	L	10.20 (1.009)	8.60 (0.934)	1.19 (1.080)
9934	L	12.54 (1.098)	13.02 (1.115)	0.96 (0.985)
10092	L	12.54 (1.098)	15.26 (1.184)	0.82 (0.927)
10243	R	Broken		
10376	L	10.14 (1.006)	13.18 (1.120)	0.77 (0.898)
10454	L	Broken		
10661	R	12.58 (1.100)	17.50 (1.243)	0.72 (0.885)
11174	L	10.60 (1.025)	13.16 (1.119)	0.81 (0.916)
11175	L	7.16 (0.855)	5.0 (0.699)	1.43 (1.223)
11176	R	10.54 (1.023)	12.20 (1.086)	0.86 (0.942)
11193	L	10.04 (1.002)	14.04 (1.147)	0.72 (0.874)
11467	R	Broken		
11468	R	Broken		
11776	L	13.54 (1.132)	12.02 (1.080)	1.13 (1.048)

Fig. 6. Bone destruction graph (after Binford, 1981) for white-tailed deer remains from Helmreich Shelter, Missouri.

anatomical parts. The MGUI lumps all ribs together as a single unit. Thus Thomas and Mayer (1983), for example, measured the maximum length of all rib fragments in a zooarchaeological collection and divided the total length of all fragments by the mean length of a rib in order to estimate the number of ribs present in the collection. Others followed suit (e.g., Grayson, 1988). Perhaps when Binford (1978) developed the MGUI, he did not distinguish different portions of the rib cage because there was at the time no analytical technique for distinguishing particular ribs. We suspect this was the case because he noted that his ethnoarchaeological informants—the Nunamiut—regularly partition a caribou (*Rangifer tarandus*) carcass into eight sets of skeletal elements including "thoracic vertebrae and the first two ribs on both sides" and "rib slabs (10 ribs each)" (Binford, 1978:60). That is, the two anteriormost ribs are separated from the more posterior ribs. In direct contradiction to this, the MGUI treats all ribs as comprising one butchering unit that is transported as a single unit. Given that
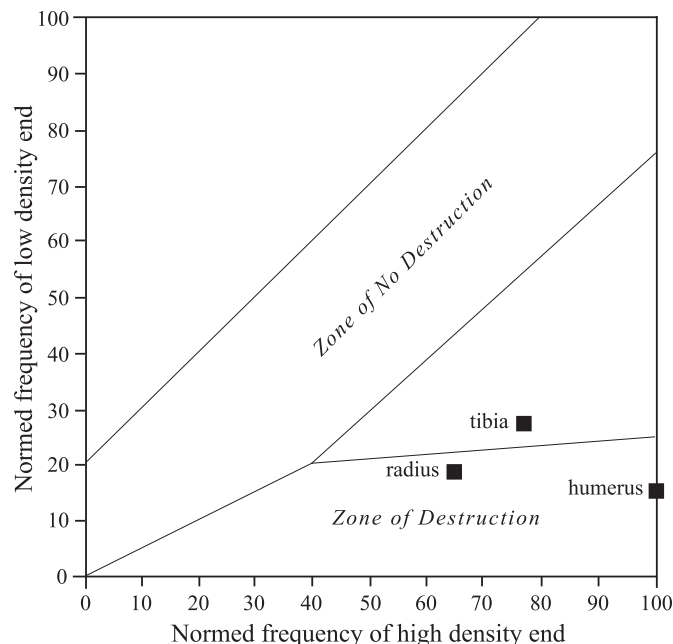
ethnographic descriptions of the butchering of other ungulate taxa sometimes mention dividing the rib cage into posterior and anterior sections of varied composition with respect to which ribs are included (e.g., Gifford-Gonzalez, 1989; O'Connell et al., 1988; Yellen, 1977), we suspect utility indices like Binford's (1978) MGUI for caribou that lump all ribs together, like the utility index developed for white-tailed deer (e.g., Madrigal, 2004) or the index developed for pronghorn (O'Brien and Liebert, 2014), consequently mask potentially significant variation in butchering and transport.

An MGUI that forces one to analytically treat all ribs as a single anatomical unit is not the only potential pitfall. Although the protocol of measuring the length of rib fragments may provide a reasonable estimate of rib abundance in a collection, using that estimate to measure economic utilization of carcasses masks variation in the distribution of consumable tissue across the rib cage. In general, the anterior portion of the rib cage has a different (greater) amount of meat associated than the posterior portion (Dolowich, 1977). It is for this reason that modern butchering practices separate the five anterior ribs from the posterior ribs in ungulates. In domestic lambs (*Ovis aries*), chops cut from the anterior rib cage, including the shoulder region, contain 27.4 g of cooked protein and 163 fat calories whereas the posterior rib chops have 25.5 g of protein and 182 fat calories (Dolowich, 1977:132–135). This suggests that when utility indices for animal taxa are developed in the future, anterior and posterior portions of rib cages should be distinguished; those portions may have different utility (food) or socioeconomic values.

Further, we would not be surprised to learn that the anteriormost ribs have different structural densities than the posteriormost ribs, and that this variable varies continuously across the rib cage. Yet each rib has been treated analytically just like any other rib in studies of the relationship between bone density and bone survivorship (e.g., Lam et al., 1999; Lyman, 2014). Similar to inferring the socioeconomic and differential transport meaning of varied frequencies of skeletal parts, those parts might suggest something about differential survival as mediated by structural density. Skeletal part frequencies have been an extremely important quantitative variable for more than three decades, in part

because of Binford's (1978) development of economic utility indices (Lyman, 2012), but also because it is a fundamental taphonomic variable given that every skeleton of, say, a deer has one skull, two mandibles, two humeri, seven cervical vertebrae, etc. (Lyman, 1994, 2008). It seems to us that if we do not distinguish rib specimens as to, minimally, anterior and posterior ribs, we may be overlooking a significant bit of taphonomic information.

Our data indicate that anterior ribs 1–6 of white-tailed deer can be distinguished from anterior ribs 9–13 of white-tailed deer based on the ratio of the log of costal facet height to the log of costal facet width. (Our data also indicate that the distinction is equally clear if non-log transformed data are used.) If that ratio is <1.0, the rib specimen is likely an anterior rib (1–6); if that ratio is >1.0, the rib specimen is likely a posterior rib (9–13). Zooarchaeological collections that include ribs of white-tailed deer can now be examined to determine whether or not anterior and posterior portions of deer rib cages are equally well represented. Deciphering why collections of rib specimens have the composition they do is the next issue with which to grapple.

Acknowledgments

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